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The main elements of the holographic installation of non-destructive testing "Sofya Varvarchuk"

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Abstract. The paper investigates the installation Sofya Varvarchuk, which refers to measuring equipment, namely, devices for monitoring the topography of the microrelief of the surface of the part, as well as devices that control defects in the geometry of the complex-shaped surface. This can be applied to the working surfaces of the blades of gas and hydro turbines, propeller blades of marine vessels, etc. Non-destructive holographic control is carried out at the installation. A holographic image of the surface is recorded, geometric characteristics are removed from it, and a three-dimensional geometric model of the surface is constructed using these characteristics. The obtained model is compared with the standard. The paper presents the latest technical developments for the Sofya Varvarchuk installation.

1 Introduction

A research laboratory was established at the Bolkhovsky Semiconductor Devices Factory (Oryol region, Russia) in 2012. Research topic: "Development of devices for non-destructive control over the formation of geometry and topography of the microrelief of the surface based on the holographic image of the object." The purpose of the scientific work: The formation of the microrelief of the surface of a complex shape according to the specified geometric characteristics in accordance with its operating conditions. Tasks:

- Describe the microrelief as a three-dimensional geometric image.
- To make a prototype of the installation of non-destructive active control over the formation of a microrelief of a complex-shaped surface.
- To make a prototype of a machine tool that allows to form, by mechanical processing, a microrelief according to the specified geometric characteristics in accordance with the operating conditions of the part.

In the expanded form, taking into account the work done, the tasks can be formulated in the following way:

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- To build a three-dimensional geometric model of a complex-shaped surface, as a superposition of the geometry of the working surface of the part and the microgeometry of its surface layer.
- To design and make prototypes: a holographic installation in the visible range of electromagnetic waves, passive non-destructive control over the formation of the geometry of a complex-shaped surface and its microrelief. Holographic installation in the range of X-ray waves (soft X-ray), active non-destructive testing (control during the processing of the part, with adjustment of processing parameters) over the formation of the geometry of the surface of a complex shape and its microrelief [1].
- To design and make a prototype of a cyclotron machine (grinding with a tool on a flexible bundle in a magnetic field), which allows mechanical processing with active control of geometric parameters of the superposition of geometry and topography of the microrelief of a surface of complex shape.

The uncertainty in the formation of the microrelief of the functional surface of the part introduced by the technological system increases due to the use of probabilistic models for predicting the result of finishing [2, 3]. In the calculation of the shaping surface of the tool, there is no calculation of its microrelief. This is due to the lack of sufficient information about the geometric structure of the microrelief, as a three-dimensional image, due to the use of a one-dimensional evaluation parameter-the height of the micro-dimensions.

This problem was solved as follows. The theoretical substantiation of the modular geometric method of modeling microrelief is given. It is known that the classification of surfaces of complex shape from a geometric point of view cannot have a scientific justification. There are no common features in the structure of the surfaces. Therefore, the surface of a complex shape is structured on the basis of the modular principle, and the structuring method is determined by the tasks of the theory of shaping. The modular-geometric method used to solve these problems consists in approximating a local area of the surface with a touching paraboloid.

An analytical representation is obtained for the contiguous paraboloid through the main curvatures of the surface. The obtained representation for the contiguous paraboloid through the main curvatures of the surface is an important result, on the basis of which a numerical calculation of the modular geometric model of the microrelief of the surface is made. A system of criteria for quantifying the topography of the microrelief is defined: k1, k2 – the main curvatures of the surface, Rz – the height of the micro irregularities. A theoretically substantiated hypothesis about the information completeness of the system of criteria for the topography of the microrelief is put forward. The geometric model of the microrelief is a set of modules having a non-smooth "stitching" - touching paraboloids. Each contiguous paraboloid can be represented as one of four types: elliptical paraboloid, hyperbolic paraboloid, cylindrical paraboloid, and plane. The method of numerical calculation of the microrelief model of a frame discretely defined surface, for example, the pen of a gas turbine blade, includes a three-dimensional geometric model of the pen, structured on the basis of a smooth crosslinking of oblique helicoids. A simulation model of the formation of a microrelief according to the specified geometric characteristics has been developed. New equations for the analytical representation of the surface formed by contiguous paraboloids with the relative movement of the tool are derived (Pat. of the Russian Federation No 2215317).

2 Holographic table

The invention relates to measuring technology, in particular, to devices for non-destructive control of the microrelief and geometry of the surface of the part and can be used for non-destructive control of the microrelief and geometry of the surface of the part [6-9]. The invention relates to measuring technology, in particular to devices for non-destructive control of the microrelief and geometry of the surface of the part.

Granite tables with pneumatic insulation are known for recording holographic images, in which high-frequency vibrations are absorbed by granite inserts, and low-frequency vibrations are absorbed by insulating the table from the external environment, and porous packaging material, pneumatic cylinders and internal pipes are used as insulation]. The disadvantages of granite tables with pneumatic insulation for recording a holographic image of an object are the lack of sufficiently effective absorption of medium-frequency and low-frequency vibrations of large amplitude, the inability to record a holographic image of medium and large-sized parts, the lack of protection against collapse of the table cover in the case of recording a holographic image of a large-sized part, as well as the inability to use the table cover to record a holographic image optical systems on a magnetic cushion. An optical holographic table with a lid is known, which contains threaded holes for mounting an optical circuit, a support - 2 - a box, tubular elements forming a cellular lattice, sound-absorbing material, and the tubular elements are made in the form of cylinders, the inner cavities of which and the gaps between them are filled with sound-absorbing material (Pat. of the Russian Federation No 1684813.

The disadvantage of this device is the inability to obtain a three-dimensional holographic image of an object based on an optical scheme for the free positioning of optical elements: mirrors, light flux dividers, spatial filters, lenses, microscope lenses, film holders, etc. The disadvantage of this device is the inability to obtain a three-dimensional holographic image of an object based on an optical scheme for the free positioning of optical elements: mirrors, light dividers, spatial filters, lenses, microscope lenses, film holders, etc.

A holographic display counter is known, including a body made of metal and supports made with the possibility of changing height (Pat. of the Russian Federation No 2781729). The disadvantages are the lack of the ability to absorb vibrations of any frequencies, the need to install on a sand cushion in a room isolated from the external environment, for example, in the basement. The UIG-2M measuring holographic installation is known, containing a pneumatic cushion, a movable part, shock absorbers, a fixed base and a working plate. The closest technical solution to the claimed one is the installation of UIG-2A, containing a duralumin working plate, - 3 - laid directly on a shock-absorbing pneumatic cushion and placed under the working plate, an associated shelf for placing a laser. The disadvantages are the lack of the possibility of free positioning of optical elements on a magnetic cushion, which leads to a decrease in the quality of holography of the object, and a low degree of protection against mechanical vibrations. The essence of the invention is explained by means of Figure 1.

Figure 1 contains eight jack supports 1, four of which are placed at the corners of the table, and the other four are two along the long sides of the table, while all supports 1 are mounted on linings 2 made of porous thick rubber 2H–1-MBS-M-2 GOST 7338-90.

Supports 1 support the base of the table made of two granite slabs 3 made of Tan Brown granite slabs (30mm), between which a gasket 4 is laid, which is a cloth made of porous rubber grade 2H-1-MBS-M-2 GOST 7338-90 Figure 2.

The base of the table is mounted on a welded metal frame 5 made of a corner Figure 3. Supports 1, made of martensitic aging steel N18K9M5T, are designed to adjust the height of the table and position its base in a horizontal plane. Four racks 6, made of 50X3.5 GOST 3262-75 pipe, are placed at the corners of the table base and mounted on it using gaskets 7, made of fluoroplast 4 GOST 10007-80, and screws 8 made of St3 steel, passed freely through holes in the table cover made of a metal plate 9 made of stainless steel 12X18H1OT GOST 5582-75, and a metal plate 10,made of electrotechnical siliceous steel E31, between which a gasket 11 is laid, which is a cloth made of damping fabric (calico 2.5X1.5m GOST 29298-2005). Racks 6 are designed to control the collapse of the table cover, i.e. in order to prevent the cover from shifting in the plane by two degrees of freedom in the case of positioning large-sized parts of large mass on it. The racks 6 are supported through granite slabs 3 and the frame 5 on supports 1.

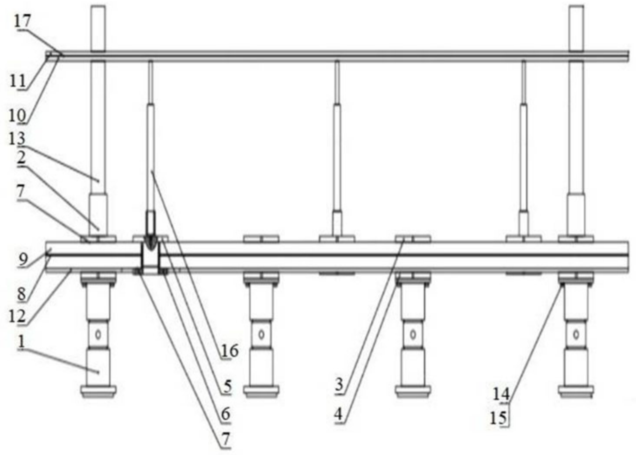

Fig. 1. Holographic table. Plan.

Fig. 2. Holographic table. View from above.

Fig. 3. Holographic table. Bottom view.

Four supports 1, not connected to the racks 6, are mounted on the base of the table using screws 12 and nuts 13 made of steel St3. All supports 1 are fixed to the frame 5 using washers 14 made of steel 8 65G 02 9 (65G high-quality steel contains 0.65 % C, alloying element 1 % Mn) and bolts 15 made of steel M8X25 GOST 7805 (high-quality alloy steel, has good strength, contains 8% Mo, 25% Cr). Six gas shock absorbers 16 filled with helium can withstand parts weighing up to 200 kg, support the table cover and are mounted on the upper granite slab 3 and frame 5 using screws 17 and nuts 18 made of St3 steel. Racks 6, supports 1 and shock absorbers 16 are fixed to the base of the table using hollow cylindrical round bushings 19. The technical task is to improve the quality of the registration process of maps, microrelief and surface geometry from the holographic image of the part. The technical result consists in the possibility of positioning small, medium and large-sized parts of large mass, the use of freely positioned schemes for recording a holographic image of a part using optical elements on a magnetic cushion, improving the quality of the registration process of maps, microrelief and surface geometry from a holographic image of a part. The essence of the invention is explained by the drawing. The positioning is free, i.e. the element can be moved in the plane of the table in any direction.

Mechanical vibrations of low frequency with high amplitude are absorbed by all damping systems of the table, including gas dampers 16, gaskets 4, 7, 11, granite slabs 3, racks 6 to control the collapse of the table cover. Medium frequency fluctuations are mainly caused by the springs of gas shock absorbers 16. High–frequency vibrations are produced by granite slabs 3, gaskets 4, 7, 11. The efficiency of the table in absorbing mechanical vibrations can be judged by the fact that the high quality of recording a holographic image of a part with free positioning of optical elements on a magnetic cushion can be estimated if there are moving heavy vehicles near the laboratory where the table is installed.

The use of the proposed holographic table for the installation of non–destructive control over the microrelief and geometry of the surface of the part allows you to make a high-quality recording of the holographic image of the part and ensure the required quality of the registration process of maps, microrelief and surface geometry from the holographic image of the part in conditions with an increased level of destabilizing factors - mechanical vibrations of various frequencies, the source of which are factory operating units. The quality of the registration of maps is determined by the established accuracy of structuring the geometric modular model of the surface of the part and the topography of its microrelief. The accuracy of the structuring lies in the range from 1nm to 1 μm.

3 Optical shutter

The invention relates to optical instrumentation, in particular, to an optical shutter and can be used in ninstallations for non-destructive testing. There are manual and electronic optical shutters, the overlap of the luminous flux in which is carried out by various types of blinds, which represent a half-plane. A common disadvantage of these devices is the inability to maintain maximum illumination of the aperture opening until the light flux is completely blocked, which worsens the quality of the holographic image of the surface of the product. As a prototype, an optical shutter (Figure 4) was selected in a light-tight housing containing a spring-loaded diaphragm, in which an axis is pivotally mounted on which the diaphragm is fixed with the possibility of rotation around an axis perpendicular to the optical axis of the shutter (Pat. of the Russian Federation No 1704130). The disadvantage of this device is the lack of the possibility of implementing a programmable exposure and preservation of maximum illumination of the aperture opening until the light flow is completely blocked by the blinds, which degrades the quality of the holographic image. The technical task that the invention is aimed at solving is to improve the quality of the process of recording a holographic image of an object by setting programmable shutter speeds.

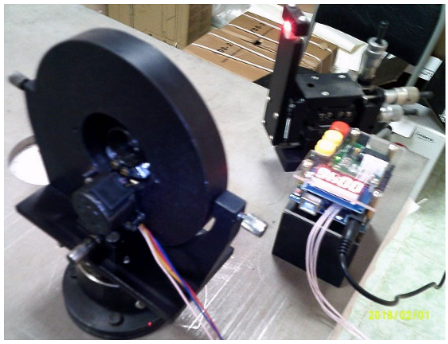

Fig. 4. Optical shutter.

The task is achieved by the fact that in an optical shutter for recording a holographic image containing a light-tight mandrel with central holes and a diaphragm mounted in them coaxially with the optical axis, the mandrel consists of two parts made in the form of discs fixed to the trunnion using screws that adjust the position of the mandrel in the vertical plane according to the angle of deviation from it, the trunnion is fixed on a plate mounted on a table that includes a knurling that serves to install the mandrel in height and is fixed with a mounting screw, the table is connected to a ball bearing , designed to adjust the mandrel according to six degrees of freedom: three translational and three rotational, with a lid and a stand fastened to each other, an adjustment screw for longitudinal feed is mounted on racks mounted on a table, a gear mounted on a holder placed under the diaphragm and connected to the motor shaft contacts the gear sector, mounted on the sector of the diaphragm containing the shutters in the central opening.

The technical result is to improve the quality of the holographic image in the process of non-destructive testing of the treated surface of the product. The essence of the invention is explained by a drawing showing a circuit of an optical shutter for recording a holographic image. The optical shutter (Figure 5) contains a light-tight mandrel 1 consisting of two parts made in the form of discs made of D16T alloy having central holes, a trunnion 2, a clamp 3, a plate 4, racks 5 and 6, covers 7 and 8, a screw 9 for adjusting the longitudinal feed of the mandrel 1, a plate 10, adjusting screws 11 for adjusting mandrels 1 in a vertical plane according to the angle of deviation from it, sector 12, toothed sector 13, holder 14, table 15, knurling 16, ball bearing 17 for adjusting mandrel 1 according to six degrees of freedom: three translational and three rotational, cover 18, stand 19, gear 20, inserted into the central hole of the mandrel 1, screws 21-25, set screw 26, washer 27, compression spring 28 and motor 29.

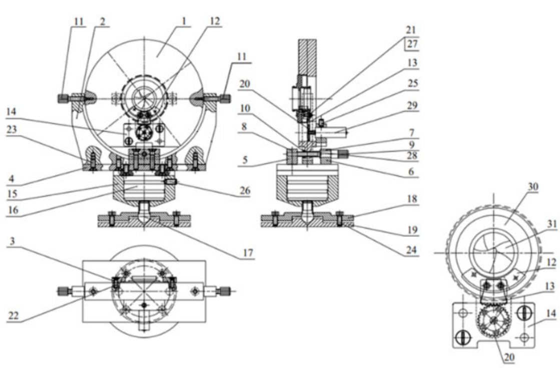

Fig. 5. Optical shutter. Plan.

Shutters 31 are built into the diaphragm 30, located in the central holes of the mandrel 1 coaxially with their optical axis. A holder 14 is placed under the diaphragm 30, supporting the motor shaft 29 connected to the gear 20 by means of a gear sector 13 in contact with a sector 12 mounted on the diaphragm 30 to engage the gear 20 and the gear sector 13.The mandrel 1, using screws 11 regulating its position in the vertical plane, is fixed to the trunnion 2, which is fixed with screws 23 on a plate 4 mounted on a table 15, including a knurling 16 inside it, which serves to install the mandrel 1 in height and is fixed with a mounting screw 26. The table 15 is connected by a ball bearing 17 with a lid 18 and a stand 19, fastened together with screws 24. Two clamps 3 on two screws 22 are mounted on a mandrel 1 to secure the inner parts of the diaphragm 30. The plate 10, covers 7 and 8, placed on racks 5 and 6, are elements of the device for mounting the adjusting screw 9 for longitudinal feeding. The operation of the optical shutter is carried out as follows.

The optical shutter is installed in front of the laser installation (not shown in the figure) so that the light beam passes through the center of the circular aperture of the diaphragm 30. The adjustment is performed using adjusting screws 11 and a ball bearing 17. During the longitudinal feeding of the mandrel 1 using the adjusting screw 9, the mandrel 1 simultaneously acquires a rotational movement along the angle of deviation from the vertical plane. On the electronic unit (not shown in the figure) connected to the engine 29, the value of the desired time interval is set from 1 to 60 seconds or from 1 to 60 minutes. Turn on the power supply of the motor 29 from the mains through the rectifier unit (not shown in the figure). The motor shaft 29 rotates at an angle (2/3)π. Toothed sector 13 connected to the drive (not indicated in the drawing, the shutter drive from the camera is used, the symbol is changed). The shutter 31 rotates the drive by an angle (2/3)π.

As a result of this rotation, the shutters 31 are disconnected and the round aperture of the diaphragm 30 opens completely. The opening and closing time of the aperture is 0.85 seconds. The opening and closing time of the blinds 31 is quite short. It is technically not possible to make it shorter. In relation to the specified time interval, it is less by an order of magnitude. Accordingly, the influence of the luminous flux on the holographic image during this time period can be neglected. After the set exposure interval expires, the direct electric current in the windings of the electric motor 29 automatically changes to the opposite direction, and the reverse movement of the motor shaft 29 is activated. The aperture of the diaphragm 30 is closed due to the overlap of the shutters 31, and until the hole is completely closed, its shape it remains constant, i.e. it is a circle that gradually shrinks to a point. The closure of the aperture of the diaphragm 30 occurs in a short period of time and the exposure time in the interval of minutes is significantly longer than the opening and closing time of the diaphragm 30, therefore, the density of the luminous flux does not change significantly, as a result of which the effect of the luminous flux on the formation of a holographic image during this period of time, the overlap of the aperture of the diaphragm 30 can be neglected.

As a result of the interference of the waves of the reference and object beams propagating in the plate emulsion, planes illuminated by light of higher intensity are formed. After the holographic image is displayed, layers of blackening are formed on the illuminated planes, i.e. Bragg planes are created, which have the property of partially reflecting light. Thus, a three-dimensional interference pattern is created in the emulsion of the recording medium. If we consider the shutter speeds determined by seconds, then, based on the fact that the illumination of the center of the aperture opening 30 remains practically unchanged, which is the result of diffraction of the flow of electromagnetic waves from the round hole in the case of rectilinear propagation of light, the effect of the luminous flux on the formation of a holographic image can be neglected and in this case the diffraction pattern can be determined by summing the actions of individual zones based on the Huygens–Fresnel principle [8]. Holographic image recording is performed on PFG-01 and PFG-03M plates using the Leith–Upatnieks, Denisyuk, etc. scheme.

4 Scanning electromagnetic field indicator

In contrast to the well-known equations of the profile of the part and the tool, which describe flat geometric models of processing, they contain fairly complete information about changes in the geometry and microgeometry of the forming and treated surface, depending on the processing modes, the parameters of the tool installation. A prototype of a holographic installation in the visible range of electromagnetic waves, passive non-destructive control over the formation of the working part of the surface of the gas turbine blade and its microrelief was developed, constructed and made, together with the specialists of the plant. The information registration system for structuring three-dimensional geometric models of the surface and its microrelief consists of a block for registering maps and a personal computer. The maps are taken from the holographic image of the microrelief (Figure 6).

Fig. 6. Scanning electromagnetic field indicator. The lens. Pin halls-two, on ball bearings.

On a personal computer, according to a specially developed program, the topography of the microrelief is automatically built. The topography of the microrelief is a three-dimensional geometric model. The card registration unit is a complex device. The mechanical "arm" has a magnetic base and is rigidly positioned on a metal plate. The magnet inside the base can be moved vertically. At the maximum height from the plate, the magnetic field is close to zero, so the arm can be moved in any direction. The "hand" fixed in a certain place can be brought to the position when the electromagnetic field sensor removes the cards. The maps are taken from the holographic image of the microrelief of the part in two mutually perpendicular directions. A CCD sensor from a video camera without an optical system is used as a sensor. The micro-motor informs the matrix of the movement by a given step. Movement control is carried out according to the appropriate scale.

The rotational motion of the motor armature is converted into the translational motion of the matrix. A worm and magnetic plates are used for this. Magnetic plates work on repulsion. The holographic system of passive non-destructive control over the characteristics of the geometry and topography of the microrelief of the surface allows you to capture information from the surface of the part. She does not "see" internal defects. For this purpose, a radioprophilograph has been developed. The installation of holographic control allows for high-precision 3D holographic control of complex profile parts up to 2000 mm × 500 mm × 1000 mm with an error of no more than 800 nanometers when working in the visible range and an error of no more than 50 nanometers when working in the X-ray range. In addition, control is carried out before and after processing, as well as during its implementation at various stages.

5 Conclusion

A table for recording a holographic image of a part, having a metal plate, has shown its effectiveness. Optical devices that have a magnetic base are used on a metal plate. The magnetic base of the devices allows you to create both classic holographic image recording schemes and schemes for exploring new possibilities for recording an enlarged image of a detail. Optical devices can be freely positioned on the metal plate of the table. This significantly reduces the setup time of the equipment. Pin halls, tables for beam dividers, mandrels for micro lenses are mounted on ball bearings. This makes it relatively easy to adjust the equipment. The main requirement for the manufacture of such equipment is high precision in the processing of individual components. The size tolerance is 0.0001 mm. Backlash and micro backlash are not allowed in the manufactured device. A stepper motor for the translational motion of the armature is under development at the plant. 1 – 10 – 100nm. This motor is planned to be used for an electromagnetic standing wave scanner in the visible range. Work is underway to create a device for recording a complete holographic image of a part.

A device for positioning the mandrel of a holographic plate is being developed. This device is a floating magnetic platform above a superconductor (Meissner effect), on which a mandrel is fixed. The superconductor is located in a bathroom made of a material that can withstand ultra-low temperatures. This material is invar.

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